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SOLE PADS AND DERMATOGLYPHICS OF THE ELK WALLOW FOOTPRINTS

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ABSTRACT: Sasquatch footprint casts from Elk Wallow (Walla Walla), previously examined in detail by Krantz (1983), are discussed with respect to the presence of a large sole pad. A sole pad is an important component in locomotion, and reconstructions of anatomy and gait must take it into account. Because large animals compensate for heavy weight principally through locomotor pattern, a large, unknown biped need not have enormous stresses acting on the moving lower limbs, but would have a gait different from living bipedal hominids. Anatomical reconstructions must also take this into account. Dermatoglyphic evidence, if abundant, can be used to reconstruct behavior. Hence, it is possible that future research utilizing prints and trackways of these large, unknown animals in the Pacific Northwest may yield more information about locomotion and behavior than is presently the case, if investigators are willing to entertain the possibility that the animals responsible for the prints may be unlike any known mammal in anatomy and locomotion. Krantz's (1983) identification of the prints as hominid, by virtue of an adducted hallux, is questioned.

INTRODUCTION

In his recent paper on the Elk Wallow (Walla Walla) Sasquatch footprints, Krantz (1983) presents a detailed summary of the configurations of three footprint casts, paying particularly close attention to dermatoglyphic data. Skepticism as to whether dermatoglyphic patterns can be preserved on plaster casts is answered by Krantz's experimental proof that a human thumbprint can be transferred from skin to soil to plaster, and by the fact that criminal identification by dermatoglyphics from footprints imprinted in soil is acceptable procedure by police departments in two countries. Krantz then investigates the dermatoglyphic patterns of the casts, and concludes from this evidence that the makers of the prints were primates. Krantz further identifies the Elk Wallow prints as made by a specific category of primates, hominids (Krantz 1983: 53)—that is, members of the zoological family to which living humans and their extinct relatives belong.

In this paper, I shall examine the sole pad, a feature of the Elk Wallow prints which Krantz does not discuss in as much detail as the dermatoglyphic evidence. This feature is, however, important for reconstructing anatomy and locomotion. I shall also examine the influence of body size on locomotion, and indicate some ways in which dermatoglyphic evidence, if more abundant, may be used to reconstruct elements of behavior. I conclude by

stressing the probability that the makers of the Elk Wallow prints are unique among mammals in terms of anatomy and locomotion, and that identification of the prints as hominid in origin, on the basis of a single trait (an adducted hallux), is incorrect.

The Sole Pad

One of the striking morphological features documented by the casts is the apparent presence of an extremely thick, flexible pad on the sole of the Elk Wallow feet. Given the impression of a stone in the middle of the "full right" cast, and a photograph of the actual print with stone in place, Krantz (1983: 64) estimates the minimal thickness of this pad as slightly greater than 2 cm in the middle of the sole. Anatomical evidence from the gorilla, largest of the living primates, indicates that a sole pad can exist with dermatoglyphic patterns intact on the plantar surface. It is therefore possible for a very large mammal to possess a thick, flexible sole pad with dermatoglyphics, and not merely ridged skin.

One might assume, by analogy with living mammals possessing such pads (Morton 1935), that the sole pad of an unknown mammal would be composed of fat and tough, fibrous connective tissue. The thick, fibrous strands would bind the skin to the deep fascia (plantar aponeurosis), and would form small compartments of firm and resilient fat. The depth of the pad might vary along the foot according to weight-bearing considerations. A sole pad is therefore a biologically normal structure, and one can use evidence from living mammals to infer its general composition in a form whose anatomy is unknown. Is it possible to estimate the depth of the sole pad in the Elk Wallow creatures using available information on sole pad thickness in living mammals? Such information exists for two primate species, gorillas and hominids.

Fat and connective tissue comprise the sole pad in the gorilla. Thick skin covers the sole of the foot, and is underlain by fat and fibrous tissue at the lateral border of the foot. The depth of this pad increases posteriorly, and reaches a maximum depth of 2.5 cm under the heel (Raven 1950: 71). In modern, bipedal humans, the sole pad is an important weight-bearing structure which is so compressible and shock-absorbing that a fall directly on the heel which shatters the calcaneus may leave no mark on the sole pad (Klenerman *et al.* 1976). The skin on the sole is thickened, especially at the heel, even in human fetuses, but the skin and the underlying pad of lobulated fat and collagen fibers is also subject to some variation in depth. Certain congenital diseases, accidents which result in the foot being placed in a cast, or prolonged bed rest may cause such thinning of the sole pad that walking is almost impossible. In acromegaly, this sole pad becomes very much thicker than normal, sometimes achieving a state "like a built-in layer of crepe rubber" (Klenerman *et al.* 1976: 137). Data on the average thickness of the human sole pad at the heel region do not seem to be readily available. In dissections of cadavers, the skin of the sole is so thick and firmly bound to the underlying lobulated fat that it is difficult to disclose the plantar aponeurosis; I would estimate a thickness of about 2 cm in the human cadaver. Histological study of the subcutaneous tissue of the gorilla foot seems to indicate a composition and thickness similar to that of man (Straus 1950: 217). An average greatest sole pad thickness of 2.5 cm may therefore be nearer the modern human norm.

Note that the sole pad is about the same thickness in hominids and gorillas, although gorilla weight is approximately three times that of hominids. I now make two assumptions. First, I assume that bipedal locomotion, in which all of the body weight is supported by the hindlimbs, experiences more selection pressure for cushioning of the foot than is the case in quadrupedal locomotion. The thickness of the sole pad in the quadrupedal, knuckle-walking gorilla would therefore be increased in a biped of gorilla size. Professional human runners, who experience impact forces at heel strike of three to five times that experienced during walking (Roy and Irvin 1983: 422), are forced to control foot movement and absorb shock with specially constructed shoes and orthotic devices. In effect, they must create artificial sole pads in addition to the natural cushioning of the sole, and even then cushioning is not always adequate to prevent injury in running athletes. This is especially the case in marathon running, where impact forces acting over a distance often cause overuse injuries. Running bipedal hominids thus experience foot impact forces several times that experienced during walking, and often suffer as a result of inadequate natural sole pads, which have been evolved to withstand walking impact. I believe that this demonstrates that, if bipedal hominid body weight were multiplied several times—the equivalent of the increase in impact force experienced during running—the thickness of the sole pad would be correspondingly increased to ensure efficient bipedal walking. In short, if gorillas were bipeds instead of quadrupeds, their average greatest sole pad thickness would perhaps be about 6–7.5 cm. I also assume that the cushioning efficiency of the sole pad in walking modern hominids is at or near the biomechanical optimum for a bipedal mammal.

If the ankle of the Elk Wallow creatures were set farther forward on the foot than is the case in modern hominids (Krantz 1983: 60), the greatest thickness of the sole pad might occur closer to the front of the foot, and not at the heel, as is the case in gorillas and hominids. The exact position of this maximum thickness would depend on the manner in which the foot contacts the substrate—that is, whether the heel or the forward part of the foot contacts the ground first (or perhaps the entire sole contacts the ground at once). It is possible, therefore, that Krantz has greatly underestimated the thickness of the pad at the middle of the sole, perhaps close to where its greatest thickness would occur. If the average thickness of the sole pad is about 2–2.5

cm in the heel region of modern bipedal hominids with a mean weight of 60 kg (Eisenberg 1981), then it is not unreasonable to reconstruct the pad on the sole of the Elk Wallow creatures as being between 10–15 cm at its greatest thickness, if these creatures are bipedal and have a weight of 400 kg, as Krantz estimates. I am simply multiplying the thickness of the hominid sole pad by six to achieve a similar kind of cushioning efficiency in an unknown bipedal mammal whose body weight may be six times greater than that of hominids. Again, this reconstruction assumes that the cushioning efficiency of the sole pad in modern hominids is at or near the biomechanical optimum for bipedal mammals. Details imprinted on the side of the Elk Wallow prints and the edges of the footprint indentations themselves indicate that an extremely flexible sole pad is present (Krantz 1983: 64–65).

A question now presents itself. If the Elk Wallow sole pad should have a thickness of 10–15 cm at its greatest depth, and should be extremely flexible, then what is the likelihood of the prints themselves preserving an extremely detailed record of anatomy and locomotion? Would not the collapse of the sidewalls of the print impressions as the foot is withdrawn obscure fine details? The print impressions would be wider at the bottom than the top, and would be subject to such collapse. Some record of wider span at the bottom seems to be preserved in the Elk Wallow prints. Slight movements of the flexible tissue of the sole would tend to erase details, even if collapse of soil at the edges of the prints did not occur. It might be that, as body weight causes compression of the sole pad, the foot would expand and extend laterally. Analysis of gait would be incomplete or inaccurate if it did not allow for these lateral shifts, which would significantly broaden the print. Very detailed analysis of locomotion by examination of footprints to yield evidence of the sequence of weight transfer (Napier 1973), and taxonomic assignation by fine examination of dermatoglyphics might therefore be subject to a certain margin of error. Only under exceptional conditions would the substrate be able to preserve an accurate picture of the living foot. The fine-grained loess soil at the Elk Wallow site may represent such conditions, but this is not the case for most areas in which prints of creatures like those presumably responsible for these prints have been collected and studied.

Another question concerns the depth of the prints themselves. If body weight is supported by such a sole pad, the large surface area of the sole would spread the weight over a relatively wide area, so that only faint tracks would be left on hard ground. In the elephant, for example, the cushioning sole pad is so thick that the foot has an externally plantigrade appearance, although the foot skeleton is held in a semidigitigrade position. That is, the elephant's heel appears externally to be touching the ground, but the animal is actually walking with the heel portion of its foot skeleton raised. The large, thick sole pad allows the animal to traverse extremely rough terrain and move silently, but the sole pad also spreads the great body weight so efficiently that individual tracks, although they cover a large area, are fainter than one might assume from the known body weight. Sikes (1971: Plate 8) shows the prints of one African elephant in firm, sandy soil. Although the print of one foot overlies the other print, pressing the soil down twice, the impressions are rather shallow. If a large sole pad spreads even massive body weight so efficiently, why do the Elk Wallow prints appear so deep? It is unlikely that the body weight exceeds the estimated 400 kg, and the sediment does not seem to have been very soft. It is possible that the sole pad of the Elk Wallow creatures is not as efficient as that of the elephant at distributing body weight over a large surface, but some type of sole pad does seem to have been present, and the estimate of its greatest depth is based on the weight inferred by Krantz (1983).

I am reasonably certain that the Elk Wallow prints are authentic. However, I do have reservations about the prints recording a precise and accurate picture of details of weight transfer. While certain portions of the casts show remarkably fine structures, Krantz (1983) is forced to select small areas from the casts to discuss dermatoglyphic evidence. This would appear to indicate that the flexible sole tissue is erasing detail. I am also puzzled by the depth of the prints. Perhaps experimentation with an artificial sole pad which could mimic the texture of the thick sole pad tissue in such mammals as camelids and elephants might resolve how much known detail can be reliably transferred from such a device onto loess soil, and thence onto plaster, and whether the dynamics of locomotion can be inferred from print and cast. The question of the depth of print impressions in relation to body weight might also be examined, if the device were capable of dissipating load like living tissue.

If the question of the depth of the impressions can be answered, the likelihood that the Elk Wallow creatures possess a large sole pad could lead to new insights into the anatomy and locomotion of such unknown animals. One interesting possibility is that the Elk Wallow creatures, like elephants, might have a semi-digitigrade foot skeleton, although the large cushioning sole pad would give the external foot a plantigrade appearance. This might account for the great amount of weight apparently carried on the forepart of the foot. Rotational movement at the ankle joint would be lost, however, so that envisioning an enlarged version of a hominid subtalar joint, for example, would be incorrect. Although Krantz (1977) has argued that the digits of the Sasquatch foot are short for biomechanical reasons, the short visible part of the digits might be arrayed at the forward edge of the sole pad, and their true length be obscured by the structure of the pad. The hindlimb anatomy and gait of the Elk Wallow creatures may be unique among mammals, and not easily inferred from comparison with living mammals of a single order, even if the dermatoglyphic evidence points to the primates.

Finally, as Napier (1973) has stressed, *trackways* of animals, and not single isolated prints, are necessary for detailed analysis of gait. Future researchers should be prepared to make casts of partial trackways—obviously not an easy task.

Body Size and Locomotion

Sasquatch foot anatomy has been examined in detail by Krantz (1977), who argues that, in comparison with living hominids, these creatures have a lengthened heel and a shortened forefoot. This leads to a reconstruction in which the ankle joint is set farther forward on the foot, a point which is also made in Krantz (1983). The power arm of the foot is thereby lengthened and the load arm is shortened. This reconstruction is derived from Krantz's belief that changing the length of the lever arms in the foot is the simplest evolutionary solution to the problem posed by large body size in bipeds. Large body size creates a problem if body weight increases cubically, while skeletal dimensions increase areally. Hence, Krantz proposes that allometric or size-related considerations affect body design in bipeds which are significantly larger than modern hominids.

Recent research on the allometry of mammalian limb bones, however, demonstrates that the lengths and diameters of limb bones in a series of species stretching from shrew to elephant-size scale close to geometric similarity (Alexander *et al.* 1979a). Obviously, there are tremendous differences in adult body mass, but the linear dimensions of the limb bones in the series are geometrically similar. For example, the elephant femur and humerus are not very much wider relative to their length than in much smaller animals. This surprising conclusion—which upsets statements on the allometric relationship between limb bone dimensions and body weight going back to the time of Galileo—also holds true within the primates, because six primate species (including modern hominids) are included in the mammalian survey (Alexander *et al.* 1979a). This research implies that the limb bones of a biped much larger than a modern hominid need not be strikingly different in form in order to support a much greater body weight.

Stresses on limb bones of moving animals versus stationary animals have also been examined (Alexander 1977, Alexander *et al.* 1979b). Because movement causes several times more stress on the limb bones than does standing still, the increase of limb bone diameter in step with length increase becomes even more surprising. How do large animals exist in spite of what appears to be a biomechanical paradox? The answer lies in gait differences. Movement patterns of different sized mammals demonstrate that the large mammals move in such a way that their limbs remain in contact with the ground for a longer time, which decreases stress in the limb bones. The reduction of relative stresses in these bones compensates for greater body weight. The maximum stresses acting on the limbs of large animals are comparable to those of smaller animals, so that the bones of the larger species do not need to be much more robust (Alexander 1977, Alexander *et al.* 1979b).

Two conclusions can be drawn from this research. The first is that unknown bipedal animals much larger than modern hominids, but hominid-like in position of the trunk and use of a striding gait in locomotion, are not an *a priori* impossibility. The second conclusion is that, because large animals compensate for heavy bodies mainly through gait pattern, differences between large, unknown bipeds and hominids might lie in the amount and length of time of foot contact with the ground, rather than in gross differences in skeletal structure.

Dermatoglyphics and the Reconstruction of Behavior

Dermatoglyphic evidence from the Elk Wallow prints is necessarily confined at present to description and taxonomic assignation. Nevertheless, it is possible that, if such evidence were to become more abundant in the future, details of behavior might be reconstructed from dermatoglyphic evidence. Primate species can be used to illustrate this contention.

There is a substantial body of data on the volar skin and dermatoglyphics of primates. Cartmill (1974, 1979) demonstrated that volar skin was subject to selection pressure involving allometry, with volar pad coalescence occurring in larger primates as an adaptation to increase its frictional characteristics. Biegert (1963) advocated the use of primate dermatoglyphics and volar pad structure as taxonomic traits, and in the reconstruction of phylogeny, but Meier (1980) reported evidence that dermatoglyphic pattern intensity in non-human primates may be more related to function than it is to taxonomy or phylogeny. The use of dermatoglyphics as indicators of biological distance in humans has equivocal results which do not necessarily coincide with biochemical or anthropometric variation (Meier 1980). This may not be the case in non-human primate species.

Dermatoglyphics appear to be useful in identifying individual animals, demonstrating group cohesiveness, and allowing analysis of introgressive hybridization in an Ethiopian site with troops of both olive and hamadryas baboons, and a troop of hybrids of these two species (Jolly and Peterson 1984). Analysis of dermatoglyphics in mantled howler monkeys on Barro Colorado Island, Panama, allowed inferences to be made about the evolutionary history of these monkeys on the island (Froehlich and Thorington 1982). Inferences about the colonization of one of the peninsulas by two different howler troops, and the differentiation of neighboring troops from a common troop are based on dermatoglyphic analysis. Thus, dermatoglyphic evidence can be used not simply for taxonomic or phylogenetic purposes, but for social and historical reconstruction as well. If the Elk Wallow prints and associated dermatoglyphics hold up under detailed scrutiny, and if many

additional prints with dermatoglyphics are found, the possibility exists that the genetic relatedness of individuals can be assessed, along with the possibility of differentiating variation at a group level, allowing inferences about the existence of social groups, gene flow, and the process of dispersal of groups or individuals within a given habitat unit.

Conclusion

There is a reasonable probability that the Elk Wallow prints were made by an unknown animal species. I have examined the presence of a large sole pad in some detail, and have reconstructed a sole pad whose greatest depth would approximate 10–15 cm. Two problems still concern me: 1) the degree to which the prints preserve undistorted information about dermatoglyphic pattern and locomotion, and 2) the depth of the print impressions, in spite of the presence of a sole pad which should efficiently distribute body weight.

I have also discussed the interaction of body weight and locomotion, and have indicated that, because large animals compensate for great weight mainly through gait pattern, gross differences in skeletal structure between large unknown bipeds and modern hominids are not necessarily to be expected. A larger biped would, however, need a greater length of time of foot contact with the ground. Furthermore, unknown bipedal animals much larger than modern hominids, but hominid-like in trunk position and use of a striding gait, are not intrinsically impossible.

If dermatoglyphic evidence similar to that from the Elk Wallow prints were to become more abundant, behavioral reconstruction could be attempted, given the lines of behavioral research that have opened recently from dermatoglyphic research in primates.

Finally, I question Krantz's identification of the Elk Wallow prints as "hominid," by virtue of the marked adduction of digit I (Krantz 1983: 53). Living primates show many variations in extremity structure. For example, New World ateline and Old World colobine monkeys independently reduced digit I in the hand, sometimes to a remarkable degree. This would be an example of the parallel evolution of a trait in two different infraorders of living primates. Conversely, it is also possible for members of a single family to show remarkable divergence in extremity structure. Thus, the African great apes develop knuckle-walking specializations of the hands while the orang-utan does not, instead lengthening the entire hand and digits II–V and reducing digit I. The foot of the orang-utan is similarly lengthened, with concomitant elongation of digits II–V, and reduction of digit I, sometimes to a vestigial state. Given the great evolutionary potential for variation in extremity structure documented in living primates, it may be problematic to identify the Elk Wallow creatures as hominids by virtue of a markedly adducted hallux. In any case, Krantz also lists a number of traits which

completely differentiate the Elk Wallow prints from those of modern or extinct hominids, such as the anterior placement of the ankle and extremely short digits. Although reported sightings of these animals emphasize similarities to hominids, and dermatoglyphic evidence points to the primate order, analysis of the prints demonstrates the existence of foot structure and locomotion unlike anything known among mammals. The prints are not simply enlarged and broadened versions of hominid prints. Therefore, the makers of the prints do not have the anatomy, body proportions, and locomotion of living hominids.

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